

## Nuclear Brightness Profiles of Merger Remnants: Constraints on the Formation of Ellipticals by Mergers

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**Abstract.** We present preliminary results of an HST/NICMOS program to image merger remnants in the J, H and K bands. The nuclear brightness profiles for most sample galaxies are similar to those typical for elliptical galaxies, but some (including the well-studied NGC 3921 and 7252) have an unusually high luminosity density at small radii. This is consistent with the prediction of N-body simulations that gas flows to the center during a merger and forms new stars.

### 1. Introduction

The possibility that many elliptical galaxies formed from mergers of disk galaxies is a topic of continuing interest. That mergers form elliptical-like remnants has been demonstrated through numerical simulations, and ground-based imaging has shown that many merger remnants have  $r^{1/4}$  luminosity profiles. These arguments, along with the detection of shells, ripples and kinematically decoupled cores in elliptical galaxies, support this ‘merger hypothesis’ (e.g., Kennicutt, Schweizer, & Barnes 1998; hereafter KSB98).

Theoretical arguments indicate that it is in the nuclei of remnants where the merger hypothesis may face its most stringent test. If dynamical relaxation is the dominant physical process in mergers, then remnant nuclei will be very diffuse with large cores (Hernquist 1992), unless the progenitor nuclei were dense to begin with. If both merging galaxies contain a central black hole, then the stellar density of the merger remnant will be lower than that of the progenitor galaxies (Quinlan & Hernquist 1997). Alternatively, if mergers are accompanied by strong gaseous dissipation and central starbursts, then the remnant may have a high stellar density and steep luminosity profile (Mihos & Hernquist 1994).

A comparison between the observed nuclear properties of merger remnants and elliptical galaxies can shed more light on the viability of the merger hypothesis and on the physical processes that govern the structure of merger remnants. The nuclear brightness profiles of elliptical galaxies have been mapped in great detail with HST. Faber et al. (1997; hereafter F97) studied a large sample of normal ellipticals. Carollo et al. (1997; hereafter C97) studied a sample of elliptical galaxies with kinematically decoupled cores (presumably old merger remnants), and found few differences as compared to the sample of F97. To complement this work, we initiated an HST study of a sample of younger merger remnants (van der Marel, Zurek, Mihos, Heckman & Hernquist 2000, in preparation), and we present here some of the preliminary results.

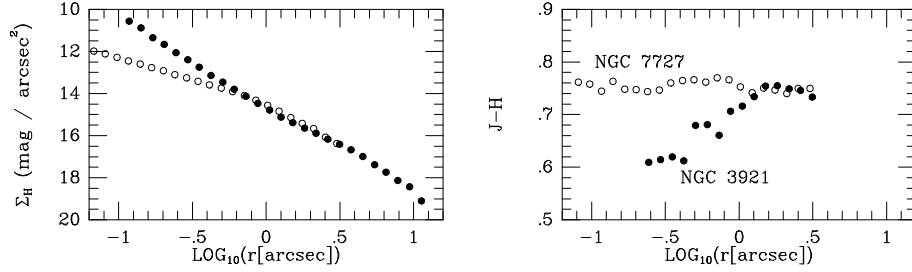


Figure 1. Solid dots show the observed H-band surface brightness profile (left) and  $J-H$  color (right) for NGC 3921. Open dots are for NGC 7727, shifted horizontally to the distance of NGC 3921. NGC 7727 has a fairly typical ‘power-law’ (F97) profile with  $I(R) \propto R^{-0.8}$  at the HST resolution limit. By contrast, NGC 3921 is unusually blue and bright at small radii, with  $I(R) \propto R^{-1.9}$ .

## 2. Sample Selection

A well-known compilation of nearby interacting galaxies and mergers is Toomre’s list of 11 galaxies selected from the NGC Catalog (see KSB98). The two latest-stage mergers in the list are NGC 3921 and NGC 7252, which have tidal tails but show no remaining signs of two galaxies with a separate identity. To create a sample for our study, we sought galaxies with morphological properties similar to NGC 3921 and 7252 from the Catalogs of Arp (1966) and Vorontsov-Velyaminov (1977), and from the imaging survey of (UV-bright) Markarian galaxies by Mazzarella & Boroson (1993). This yielded a sample of 19 galaxies with  $cz < 10000 \text{ km s}^{-1}$ , of which we imaged 14 galaxies (including NGC 3921 and 7252). The remaining five galaxies are classified as ultra-luminous IR galaxies, and were imaged with HST by other teams.

## 3. Observations

To minimize any influence of dust on the observed brightness profiles we observed the galaxies in the near-IR with the HST/NICMOS instrument (Cycle 7 project GO-7268). Images were obtained with the NIC2 camera (pixel size  $0.076''$  square) using the filters F110W, F160W and F205W, corresponding roughly to J, H and K, and with the NIC1 camera (pixel size  $0.043''$  square) only in F110W. Each image was subjected to basic reduction steps followed by Lucy deconvolution with an appropriate PSF. Azimuthally averaged brightness profiles were extracted for all camera/filter combinations. Example results for two galaxies are shown in Figure 1.

Each brightness profile was fit by a ‘nuker’ law (Lauer et al. 1995), which was deprojected to obtain the three-dimensional luminosity density. Figure 2 shows this density in the  $H$ -band at a fiducial radius  $r = 50 \text{ pc}$ , as function of galaxy luminosity (assuming  $H_0 = 80 \text{ km s}^{-1} \text{ Mpc}^{-1}$ ), both for the galaxies in our sample and for those in the samples of F97 and C97 (transformed to the  $H$ -band under the assumption of a proto-typical  $V-H = 3.0$  for elliptical

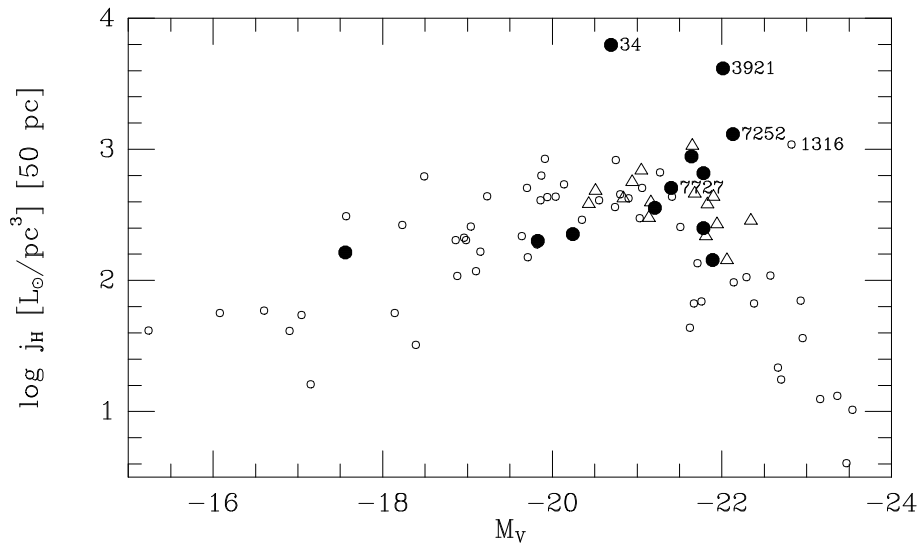


Figure 2. Three-dimensional  $H$ -band luminosity density at  $r = 50$  pc as function of  $M_V$ . Solid dots are the galaxies in our HST/NICMOS sample. Open dots and triangles are galaxies from F97 and C97 respectively. NGC numbers are indicated for selected galaxies.

galaxies; Peletier, Valentijn & Jameson 1990; Silva & Bothun 1998). While most of the galaxies in our sample follow the same approximate correlation as normal ellipticals, there are three galaxies that strongly stand out because of their high luminosity density: NGC 34, 3921 and 7252. One other galaxy that stands out for the same reason is NGC 1316 from the F97 sample, which is also a merger remnant (Schweizer 1980).

The  $J - H$  and  $H - K$  color profiles of NGC 3921 and 7252 show that they become bluer towards the center, presumably due to recent star formation. This is consistent with the detection of strong Balmer absorption lines in ground-based spectra of these galaxies (KSB98). NGC 34 becomes redder towards the center, probably as a result of dust absorption. NGC 34 is the most IR-luminous galaxy of those that we observed, suggesting the presence of ongoing or recent star formation in this galaxy as well.

#### 4. Discussion and Conclusions

The high luminosity densities observed in NGC 34, 3921 and 7252 are probably a direct consequence of recent star formation triggered by a merger. Stellar populations fade with time, and these galaxies will therefore become more similar to normal ellipticals as time passes. Dynamical and spectral evidence suggest that the mergers happened 0.5–1.5 Gyr ago (KSB98). The models of Bruzual & Charlot (e.g., 1993) indicate that a single-burst population fades by a factor of  $\sim 10$  between 0.5 and 10 Gyr. Figure 2 therefore suggests that these galaxies may become similar to normal ellipticals within a Hubble time. Most galaxies in our sample are already now similar to normal ellipticals in terms of their nuclear

luminosity density, although some fall on the high end of the range occupied by normal ellipticals. If these galaxies are the remnants of disk-disk mergers, then either the merger ages must be large so that the newly formed stars have mostly faded, or they never formed many new stars, e.g., because the progenitors were gas poor or the star formation efficiency was low.

Results such as those for NGC 3921 in Figure 1 indicate that its star formation was limited mostly to the central region,  $r < 0.5'' \approx 200$  pc. This is consistent with predictions of dissipative N-body simulations of disk-disk mergers, in which the gas quickly falls to the central few-hundred pc (Mihos & Hernquist 1994). The ‘excess’ light in the central arcsec of NGC 3921 (as compared to NGC 7727; see Figure 1) represents  $\sim 4\%$  of the total galaxy luminosity, and probably a smaller fraction in terms of mass. CO complexes observed in the central kpc of merger remnants support the view that gas flows to the center in galaxy interactions, but even if all the CO observed in NGC 3921 and 7252 were soon turned into stars, the light from recently formed stars would still provide only a small fraction of the total galaxy luminosity (Hibbard & Yun 1999).

To summarize, we have detected the luminosity spikes predicted by dissipative simulations of disk-disk mergers, but only in some of our galaxies. In general, it appears that the light from young stars does not provide a major contribution to the total galaxy luminosity. This is consistent with work by Silva & Bothun (1998), who found that the near-IR colors of most morphologically disturbed ellipticals are inconsistent with intermediate age (2–5 Gyr) stars providing much of the luminosity. This raises the question whether these galaxies were ever similar to ultra-luminous infrared galaxies, in which massive starbursts are known to occur as a result of galaxy interactions.

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